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Shashlyk Calorimeter in KOPIO GEANT

Reference Manual

Version 0.2 January 26, 2004

1 Introduction

The KOPIO electromagnetic calorimeter is being designed as an 48×48 array (Fig. 1) of the Shashlyk modules (Fig. 2). **WARNING: some details in the shown pictures are already obsolete.**

A detailed discussion of the photon and electron detection in the Shashlyk calorimeter is given in KOPIO Technote 15.[1]

Only subroutines essential for the description of the geometry of the calorimeter are reviewed in this note. The digitization of the hits in the calorimeter is not considered.

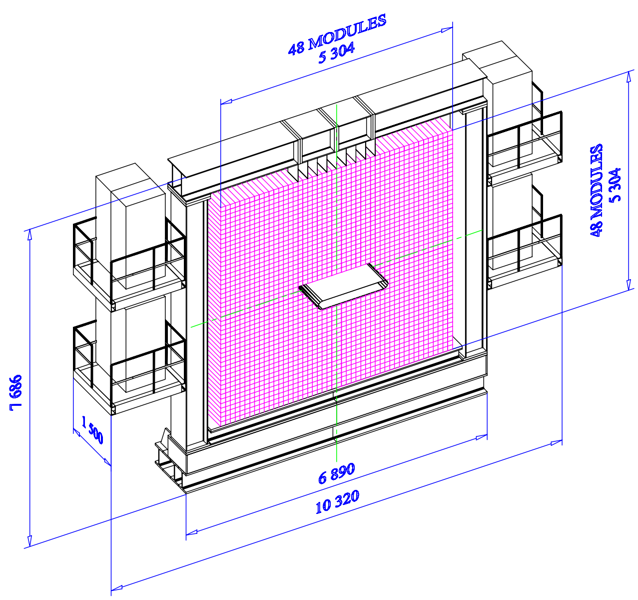

Figure 1: The Shashlyk calorimeter.

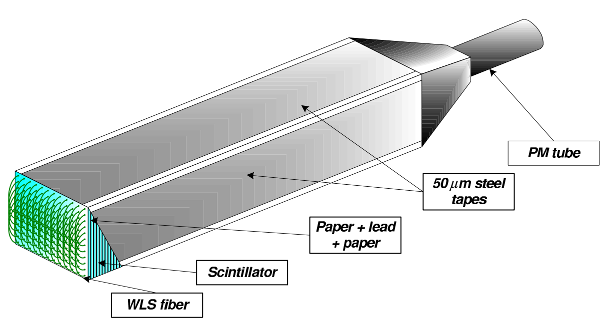

Figure 2: The calorimeter module.

[1]See also G.S. Atoian *et al.*, e-Print Archive: physics/0310047

2 Files

The Shashlyk geometry package for the GEANT KOPIO contains following files:

kopio_shashlyk_private.inc
kopio_shashlyk.inc
kopio_shashlyk.F
kopio_shashlyk_frame.F
kopio_shashlyk_sandwich.F
kopio_shashlyk_soup.F
kopio_shashlyk_init.F
kopio_shashlyk_materials.F
kopio_shashlyk_gstpar.F
kopio_shashlyk_optics.F
get_tmed.F
get_last_tmed.F
get_last_mate.F
get_rotm.F
gurndm.F
gunorm.F
kopio_shashlyk_opteff.dat

The include files *.inc contain the parameters necessary for the simulation of the KOPIO Shashlyk calorimeter. The file kopio_shashlyk_private.inc is supposed to be privately used by the Shashlyk geometry subroutines `kopio_shashlyk*.F` while the file kopio_shashlyk.inc will provide all necessary Calorimeter information to other parts of KOPIO GEANT, e.g. to the Shashlyk digitization subroutines.

Files with extension .F contain only one FORTRAN subroutine or function with the same name. Subroutines get_* and functions gurndm and gunorm are independent of the Shashlyk geometry parameters and may be used in any GEANT3 environment.

The ASCII file kopio_shashlyk_opteff.dat contains the light collection efficiency matrix for the Shashlyk scintillator plate.

3 Parameters for simulation (kopio_shashlyk_private.inc)

File kopio_shashlyk_private.inc contains the list of parameters essential for the describing the geometry of the calorimeter and for the simulating the response of the calorimeter. `calEMC`, the calibration coefficients which relate the "visible" energy deposited in the scintillator with the total energy of the photon or electron, and `sigEMC`, the contribution of the module sampling and shower leakage to the energy resolution, were obtained in special simulation. Any change of the module geometry or light attenuation length in the WLS (wave length shifting) fibers will require the modification of this parameters.

It is supposed that any parameters in this file may be changed by the experts only.

The full list of the parameters included to the file kopio_shashlyk_private.inc is shown below. The identifiers declared as FORTRAN constants (parameters) are underlined.

Identifier	Type	Value	Description
NxEMC	integer	48	Total number of modules in x-direction
NyEMC	integer	48	Total number of modules in y-direction
NxEMCh	integer	2	The size (number of modules) of beam pipe hole in x-direction
NyEMCh	integer	48	The size (number of modules) of beam pipe hole in y-direction
dEMC	real	11.0	The effective transverse size of the calorimeter module including the gap between modules.
dEMCp	real	0.01	The thickness of the paper wrapped around the module.
dEMCm	real	10.97	The transverse size of the lead/scintillator sandwich.
nEMCpl	integer	300	number of layers in the lead/scintillator sandwich.
dEMCPb	real	0.0275	The thickness of the lead plate
dEMCSc	real	0.15	The thickness of the scintillator plate.
dEMCGp	real	0.00125	The gap between lead and scintillator plates.
nFibr	integer	12	Number of WLS fibers in x or y direction. Total number of fibers is nFibr×nFibr.
sFibr	real	0.93	The distance between fibers.
dEMCfhl	real	0.13	The diameter of the WLS fiber hole in the lead plate.
dEMCfhs	real	0.13	The diameter of the WLS fiber hole in the scintillator plate.
dEMCfb	real	0.10	The WLS fiber diameter.
dEMCcl	real	0.006	The thickness of WLS fiber cladding. **(Currently not used in the simulation)**.
sxWire	real	6.01	The distance between steel wires (x-direction).
syWire	real	5.58	The distance between steel wires (y-direction).
dEMCwhl	real	0.11	The diameter of the steel wire hole in the lead plate.
dEMCwhs	real	0.11	The diameter of the steel wire hole in the scintillator plate.
dEMCwr	real	0.10	The diameter of the steel wire.
dEMCcap	real	3.7	Full length of the front end cap.
dEMCcpx	real	10.00	Transverse size of the front face of the cap.
dEMCcpw	real	0.75	Thickness of the base of the cap. (The effective thickness of the fiber loops is included)
dEMCcpt	real	0.2	The thickness of the cap walls.
dEMCcps	real	7.44	The distance between cap's holders.
dEMCcpd	real	0.8	The diameter of the cap holder
CALO	character*4	'CALO'	The set identifier for the Calorimeter sensitive detector.

SHSC	character*4	'SHSC'	The detector identifier for the Calorimeter sensitive detector. The volume name for the Shashlyk sensitive material (scintillator).
SH_M	character*4	'SH_M'	The volume name for the Shashlyk module.
SH_Z	character*4	'SH_Z'	The volume name for the Shashlyk module layer.
nEMCtype	integer	3	Number of supported types of modules.
kEMCmixture	integer	1	The module type for the lead/scintillator mixture.
kEMCsandwich	integer	2	The module type for the lead/scintillator sandwich, no light collection efficiency..
kEMCopteff	integer	3	The module type for the lead/scintillator sandwich with light collection efficiency matrix.
attEMC(nEMCtype)	real	Table 1	Effective light attenuation length in WLS fiber.
calEMC(nEMCtype)	real	Table 1	Energy calibration factor. It is approximately equal to the ratio of the total and visible energies corrected by the light attenuation in WLS fibers.
sigEMC(nEMCtype)	real	Table 1	Simulated energy resolution $\left(\times\sqrt{E\ (\mathrm{GeV})}\right)$ without photo-statistics.

4 User parameters (kopio_shashlyk.inc)

Since file kopio_shashlyk_private.inc contains crucial parameters for the KOPIO calorimeter simulation, it is assumed that this file will be employed **only** by the calorimeter geometry related subroutines.

However some of the parameters, e.g. module size, are necessary for the analysis of the data simulated by GEANT. Such kind of information may be obtained from the common block /EMC_param/ described in the file kopio_shashlyk.inc.

The parameters included to this common block may be separated into 3 groups:

Parameters customizing the calorimeter performance. The values of the parameters iEMCtype, CeresEMC, dz_PR_EMC which are entered via input cards geometry.kopio.ffread are essential for the event simulation by KOPIO GEANT.

iEMCtype	attEMC	calEMC	sigEMC	Comment
1	—	1.03485	0.01451	A block of Lead/scintillator mixture.
2	310.	3.25455	0.02833	Lead/scintillator sandwich. Light collection is not simulated.
3	310.	3.30267	0.02828	Lead/scintillator sandwich. The (relative) light collection efficiency in the scintillator plate is in accordance with kopio_shashlyk_opteff.dat

Table 1: Description of the considered types of Shashlyk modules.

The iEMCtype identifies the predefined properties of the Shashlyk module as shown in Table 1.

The CphstEMC specifies the expected energy resolution (for 1 GeV photon) of the calorimeter. It is used to define CphstEMC the photo-statistics contribution to the energy resolution. See the description of CeresEMC and CphstEMC for more details.

The dz_PR_EMC specifies the distance between back end of the Preradiator and the reference point of the calorimeter. The *reference point of the calorimeter* is defined as the center of the front face of the active (scintillator) part of the calorimeter.

Parameters customizing the interpretation of the signals from the calorimeter. Parameters CcorrEMC, CnoiseEMC, CcoheEMC, CfibrEMC entered via geometry.kopio.ffread are not used in the simulation of the electromagnetic showers. However they might be useful for the customizing of the signal from the calorimeter. See Section 8 for the suggested usage of this parameters.

Parameters describing the geometry of the Shashlyk calorimeter. This parameters are derived in subroutine kopio_shashlyk_init from the Shashlyk module parameters entered in the file kopio_shashlyk_private.inc. The main reason for such duplication of the parameters describing the module geometry is to keep the include file kopio_shashlyk_private.inc only for using by the Shashlyk geometry subroutines. The common block /EMC_param/ described in kopio_shashlyk.inc is suggested for use in other subroutines of KOPIO GEANT. FORTRAN constant (parameter) NVEMC which declare the number of volume descriptors for the calorimeter sensitive detector is displayed in this group of the parameters.

Identifier	**Type**	**Value**	**Description**
iEMCtype	integer	1	Shashlyk module type (see Table 1).
dz_PR_EMC	real	5.	The distance between back end of Preradiator and reference point of Calorimeter.
CeresEMC	real	0.03	The anticipated energy resolution of the Calorimeter. The value of CeresEMC is used to define CphstEMC, the photo-statistics contribution to the energy resolution. Since the energy resolution depends on the method of the data processing, CeresEMC is not the exact value of the energy resolution, but only an approximation with few percent accuracy. In other words, this is only a parameter to customize the effect of the photo statistics in the simulation.
CcorrEMC	real	1.	Additional normalization factor for the energy measured in the calorimeter.
CnoiseEMC	real	0.	Incoherent noise (GeV) contribution per module to the energy resolution.
CcoheEMC	real	0.	Coherent noise (GeV) contribution per module to the energy resolution.
CfibrEMC	real	0.5	Effective speed of the signal propagation in the WLS fiber (in units of speed of light in vacuum).

CphstEMC	real	$\sqrt{\texttt{CphstEMC}^2 - \texttt{sigEMC(iEMCtype)}^2}$	
			Photo-statistics contribution to the energy resolution of the Shashlyk module. (CphstEMC=0 if CeresEMC $\leq$ sigEMC(iEMCtype))
CnormEMC	real	calEMC(iEMCtype)	
			The gain calibration.
fattEMC	real	attEMC(iEMCtype)	
			Effective light attenuation length in WLS fiber.
nEMCtot	integer	NxEMC $\times$ NyEMC	
			Total number of shashlyk modules, including the ones "removed" from the beam pipe hole.
nxEMCtot	integer	NxEMC	The width of the calorimeter in module units.
nyEMCtot	integer	NyEMC	The height of the calorimeter in module units.
nxEMChole	integer	NxEMCh	The width of the beam pipe hole in the calorimeter in module units.
nyEMChole	integer	NyEMCh	The height of the beam pipe hole in the calorimeter in module units.
xEMC	real	dEMC	The transverse size of the module in x-direction
yEMC	real	dEMC	The transverse size of the module in y-direction
zEMC	real	nEMCpl $\times$ (dEMCPb + dEMCSc + 2 $\cdot$ dEMCGp)	
			The length of the lead/scintillator sandwich
zEMCcap	real	dEMCcap	The length of the front face cap.
nzEMC	integer	nEMCpl	Number of layers in the lead/scintillator sandwich.
dzEMC	real	dEMCPb + dEMCSc + 2 $\cdot$ dEMCGp	
			The thickness of one layer of the lead/scintillator sandwich.
nameEMCset	character*4	CALO	The GEANT set identifier for the calorimeter sensitive detector.
nameEMCdet	character*4	SHSC	The GEANT detector identifier for the calorimeter sensitive detector.
NVEMC	integer	2	Number of volume descriptors for the calorimeter sensitive detector. NVEMC is declared as FORTRAN constant (parameter) in kopio_shashlyk.inc.
nameEMC(1)	character*4	SH_Z	First element of the calorimeter volume descriptor array associated with the layer of the lead/scintillator sandwich. If iEMCtype $\neq$ 1 the layers are numerated from 1 to nEMCpl in the direction of z-axis. If iEMCtype = 1 the layers SH_Z are not defined.
nameEMC(2)	character*4	SH_M	Second element of the calorimeter volume descriptor array, associated with the Shashlyk module. The order of the modules numeration is shown in Fig. 3.

5 FORTRAN subroutines and functions

In the description of the subroutine calling sequences, the output arguments are followed by *. The subroutines having names started with 'kopio_shashlyk...' are specific for the description of the KOPIO Shashlyk geometry while subroutines 'get_...' may have common GEANT use.

call kopio_shashlyk

This subroutine is used for consistency with previous versions.
Currently it is used exclusively to call kopio_shashlyk_frame

call kopio_shashlyk_frame(CHMOTH,x,y,z,IROT)

CHMOTH	(character*4)	the name of the volume in which calorimeter is positioned;
x	(real)	x-position of the calorimeter reference point† in CHMOTH;
y	(real)	y-position of the calorimeter reference point† in CHMOTH;
z	(real)	z-position of the calorimeter reference point† in CHMOTH;
IROT	(integer)	rotation matrix number describing the orientation of the calorimeter relative to the CHMOTH.

† *The calorimeter reference point is the center of the front face of the active (scintillator) part of the calorimeter.*

The main subroutine to construct Shashlyk calorimeter.

First, it calls kopio_shashlyk_init to initialize the definitions of the Shashlyk calorimeter parameters and to create the description of the Shashlyk module SH_M.

The calorimeter is described as four logical containers, SH_1, SH_2, SH_3, SH_4 located around the beam pipe hole (Fig. 3). Shashlyk modules are positioned individually in the containers. Such structure allows us to combine the simple description of the calorimeter (only four volumes for outer observer) with the straightforward numeration of the modules with no respect to the boundaries of the logical containers and beam pipe hole as shown in Fig. 3. The direct positioning of modules in the containers instead of positioning by the x

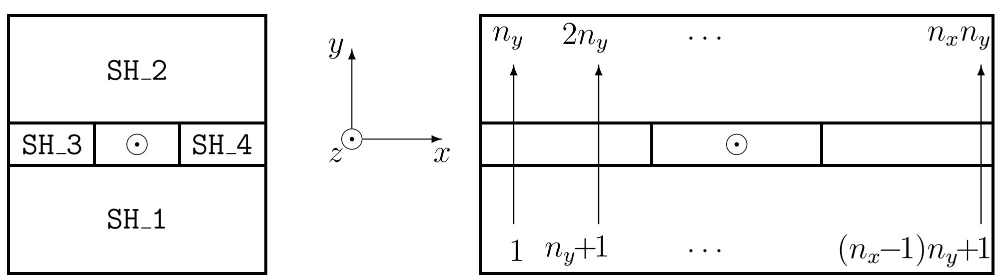

Figure 3: Positioning of the logical containers (left) and numeration of the calorimeter modules (right). n_x and n_y are the total number of modules in x and y directions. Modules "removed" from the beam pipe hole are also numbered. Beam (z-axis) is directed out of the page.

and y division of the container, slows down the speed of the photon shower simulation by only few percent.

Containers SH_1, SH_2, SH_3, SH_4 are positioned in the volume CHMOTH in accordance with the coordinates x, y, z of the calorimeter reference point and in accordance with the rotation matrix IROT describing the orientation of the calorimeter relative to the CHMOTH.

Finally, a sensitive detector for the Shashlyk calorimeter is defined with the set identifier CALO, the detector identifier SHSC and $mathttNVEMC = 2$ volume descriptors SH_Z (layer number) and SH_M (module number).

call kopio_shashlyk_sandwich

This subroutine provides the detailed description of the geometry of the Shashlyk module SH_M. The volume SH_M includes SH_P, the lead/scintillator sandwich wrapped into the paper, and SHC1, the plastic cap which covers the fiber loops on the front face of the Shashlyk module (Fig 4). The transverse size of the SH_P is slightly less than the total size of the module, which takes into account an anticipated gap between the modules in the calorimeter assembly.

The volume SH_P is divided longitudinally in nEMCpl (=300) layers SH_Z. The scintillator plate SHSC, the lead plate SHLD, and the air gaps SHGP are positioned into the SH_Z.

The scintillator SHSC and lead SHLD plates contain nFibr×nFibr (=144) holes SHSH and SHLH, respectively, with the elements of the WLS fibers SHSF and SHLF. The air gap contains the same number elements of the fibers SHGF.

Similarly, in each plate there are 4 hole/wires SHSI/SHSW, SHLI/SHLW, SHGW which describe the module compression wires, made of steel

The material of the fiber loops inside the cap SHC1 is taken into account by appropriately increasing the thickness of the cap base.

call kopio_shashlyk_soup

This subroutine provides the simplified description of the geometry of the Shashlyk module. While the dimensions of the module SH_M are the same as in subroutine kopio_shashlyk_sandwich, the active part of the module, SHSC, is described as a uniform volume of the lead/scintillator mixture with density 2.6 g/cm^3. The length of the volume SHSC is the same as length of the volume SH_P in kopio_shashlyk_sandwich, and the transverse size is the same as the size of SH_M, i.e. no gaps between modules are accounted. The volume SH_Z is not defined in this subroutine.

The cap SHC1 is approximated by a uniform plastic box containing the same amount of materials as the real cap (with fiber loops).

call kopio_shashlyk_init

The common block /EMC_param/ (Section 4), which contains the Shashlyk related information for the processing of the simulated hits in the calorimeter is filled.

It is assumed that such parameters as iEMCtype, the considered type of Shashlyk module, and CeresEMC, the anticipated energy resolution (for 1 GeV photons), are already defined via geometry.kopio.ffread. In kopio_shashlyk_init the CeresEMC is used to set the photo-statistics contribution to the energy resolution

$$\mathtt{CphstEMC} = \begin{cases} 0. & \text{if } \mathtt{CeresEMC} < \mathtt{sigEMC(iEMCtype)} \\ \sqrt{\mathtt{CeresEMC}^2 - \mathtt{sigEMC(iEMCtype)}^2} & \text{if } \mathtt{CeresEMC} \geq \mathtt{sigEMC(iEMCtype)} \end{cases}$$

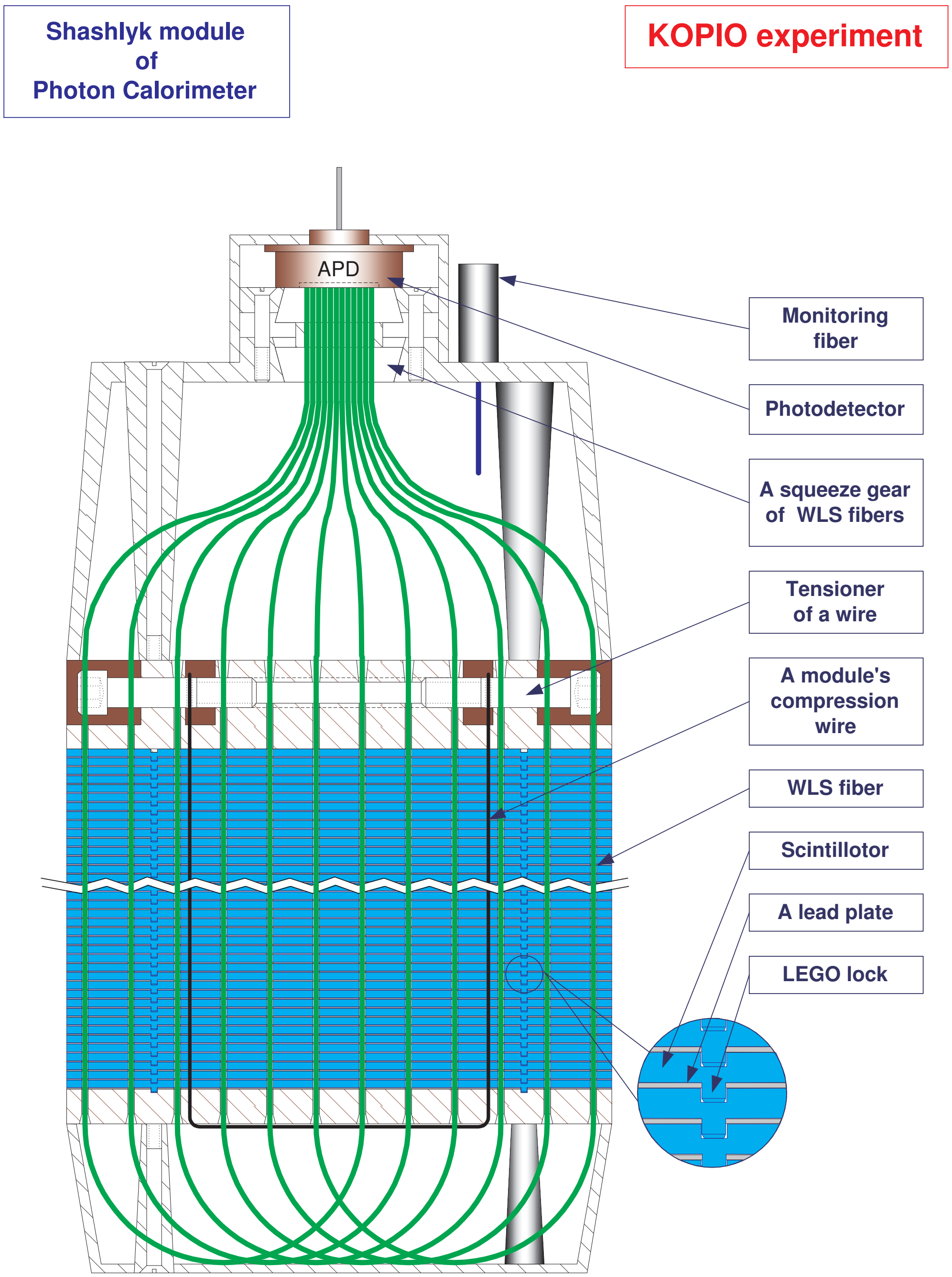

Figure 4: Some details of the Shashlyk module design

The elements of the /EMC_param/ describing the geometry of the Shashlyk calorimeter are derived from the kopio_shashlyk_private.inc parameters.

The materials and tracking media used for the description of the Shashlyk calorimeters are defined via a call to the subroutine kopio_shashlyk_materials. The special parameters associated with Shashlyk tracking media are set in the subroutine kopio_shashlyk_gstpar.

Depending on the selected type of the Shashlyk modules, `iEMCtype`, the subroutines describing the geometry of the module, kopio_shashlyk_sandwich or kopio_shashlyk_soup are called.

call kopio_shashlyk_materials

A proper simulation of the electromagnetic shower in the Shashlyk module assumes the special settings of the tracking media options, such as energy cuts and generation of δ-rays. To make this parameters independent of the requirements of other KOPIO GEANT detectors, all materials and tracking media used by the calorimeter were explicitly defined. The following names of materials and tracking media were used: `SHASHLYK_AIR`, `SHASHLYK_FIBER`, `SHASHLYK_SCNT`, `SHASHLYK_LEAD`, `SHASHLYK_PAPER`, `SHASHLYK_IRON`, `SHASHLYK_MIXTURE`.

To avoid conflict with the material and tracking media numbers declared in other parts of the KOPIO GEANT program, first, the largest numbers of material and media in use are determined with subroutines get_last_mate and get_last_tmed. Incrementing these numbers the corresponding numbers for Shashlyk simulation are obtained. Using the tracking media name, the corresponding media number may be extracted via subroutine get_media_number.

In KOPIO GEANT, the regular definition of the materials and tracking media is done in the subroutine kopio_materials. Since this subroutine is called prior kopio_shashlyk_materials no conflicts between Shashlyk and other kopio materials can occur. **If some materials will be defined after the call to kopio_shashlyk_materials, it is recommended to determine acceptable material and media numbers with subroutines get_last_mate and get_last_tmed.**

call kopio_shashlyk_gstpar

This subroutine is used to set the special tracking parameters for the Shashlyk related media.

If `iEMCtype=1` (lead/scintillator mixture), the electron and photon energy cuts are set to 100 KeV and δ-ray production is turned off, `IDRAY=0` and `ILOSS=2`.

If `iEMCtype=2,3` (lead/scintillator sandwich), the electron and photon energy cuts are set to 10 KeV and δ-ray production is turned on, `IDRAY=1` and `ILOSS=3`.

call kopio_shashlyk_optics(`x,y,Ehit,Edet*`)

`x`	(real)	x-coordinate of the hit relative to the center of the scintillator plate;
`y`	(real)	y-coordinate of the hit relative to the center of the scintillator plate;
`Ehit`	(real)	energy deposited in scintillator (GeV);
`Edet`	(real)	energy deposited in the WLS fiber (arbitrary units).

If `iEMCtype=3` then this subroutine accounts light collection efficiency in the scintillator plate:

$$\texttt{Ehit} \Rightarrow \texttt{Edet}.$$

If `iEMCtype=1,2` then independently of the coordinates `x` and `y` of the hit:

$$\texttt{Edet} = \texttt{Ehit}$$

call get_tmed(CHNAME,itmed*)

CHNAME	(character*20)	tracking media name;
itmed	(integer)	tracking media number.

Returns the tracking media number `itmed` for the given tracking media name `CHNAME`. **If the tracking media `CHNAME` does not exist, the program STOPS.**

call get_last_tmed(itmed*)

itmed	(integer)	tracking media number.

Returns the last (largest) tracking media number already defined.

call get_last_mate(imate*)

itmed	(integer)	user material (mixture) number.

Returns the last (largest) user material number already defined.

call get_last_rotm(IROT*,THETA1,PHI1,THETA2,PHI2,THETA3,PHI3)

IROT	(integer)	number of the rotation matrix;
THETA1	(real)	polar angle for axis x';
PHI1	(real)	azimuthal angle for axis x';
THETA2	(real)	polar angle for axis y';
PHI2	(real)	azimuthal angle for axis y';
THETA3	(real)	polar angle for axis z';
PHI3	(real)	azimuthal angle for axis z'.

For the given polar and azimuthal angles of the axes of the Daughter Reference System (x', y', z') in the Mother Reference System returns the number of the rotation matrix in the data structure `JROTM`.

If the searched matrix does not stored in the `JROTM`, the new matrix (with the first number not already stored in `JROTM`) is created via the routine `GSROTM` and its number is returned.

This subroutine is not currently used in the Shashlyk geometry subroutines, however it might be useful if the rotations of the calorimeter will be considered.

value = gurndm(a,b)

a	(real)	tracking media number;
b	(real)	tracking media number.

Returns a random number uniformly distributed in the interval (a, b). The standard GEANT random number generator `GRNDM` is used.

This function is not currently used by the Shashlyk geometry subroutines, but it might be useful in the digitization stage.

value = gunorm(sigma)

sigma	(real)	RMS (sigma) for Gaussian distribution.

Returns a random number distributed according to the normal (Gaussian) distribution with mean value equal to 0 and RMS equal to `sigma` The standard GEANT random number generator `GRNDM` is used.

This function is not currently used by the Shashlyk geometry subroutines, but it might be useful in the digitization stage.

6 Light collection efficiency matrix (kopio_shashlyk_opteff.dat)

To take into account light collection efficiency, subroutine kopio_shashlyk_optics employs the table stored in the file kopio_shashlyk_opteff.dat. In this file, the light collection efficiencies for the x-y coordinate grid with the step 1 mm are given in ASCII format. This file was prepared in a special standalone simulation of the light propagation in the Shashlyk scintillator plate. The method is briefly described in KOPIO Technote 15. The results of such calculations strongly depends on the optical properties of the surfaces involved into the consideration. The optical properties were adjusted in the simulation of the special measurements performed with a *single* scintillator plate. Since no experimental measurements of the uniformity of the Shashlyk module response have been done recently, the quality of the light collection efficiency table remains questionable.

However, almost negligible influence of the light collection efficiency on the results of the GEANT simulation (see Section 9) allows us to expect that further tuning of the optical model will not significantly affect the results of KOPIO GEANT simulation of the Shashlyk module.

7 Definition of the Shashlyk sensitive detector

A conventional way of the processing of the GEANT generated hits is provided by GEANT data structures `JSET, JHITS, JDIGI`. Since the declaration of the sensitive detector *set* is heavily referred to the volume names, it is convenient to define the set for the Shashlyk calorimeter inside the Shashlyk geometry package. This is done in the subroutine kopio_shashlyk_frame. The set identifier `nameEMCset`, the detector identifier `nameEMCdet`, and the array `nameEMCNVEMC` which are included to the common block `/EMC_param/` (kopio_shashlyk.inc) are associated with the kopio_shashlyk_private.inc character*4 constants `CALO, SHSC, EMC_Z, EMC_M`. The same constants are used for the definition the corresponding volume names.

For the described definition of the set, the Shashlyk layer and module numbers where hit occur may be obtained via array `NUMBV` in the common block of gcvolu.inc. If `iEMCtype` $= 2, 3$ (lead/scintillator sandwich), `NUMBV(1)` contains the layer number, which runs values from

1 to nEMCpl (=300) increasing in the z-axis direction. If $\texttt{iEMCtype} = \texttt{1}$ (lead/scintillator mixture), $\texttt{NUMBV(1)} = \texttt{0}$. NUMBV(2) contains the module number (see Fig. 3).

8 Simulation of the calorimeter response

The following scheme of the calculating of the energy deposited in the calorimeter is proposed.

- **Storing the hits**

  1. Every energy loss (DESTEP≠0) in the calorimeter sensitive volume should be stored to the hit bank.
  2. Saturation of the scintillator should be taken into account DESTEP ⇒ Ehit by a call to the GBIRK subroutine:

     $$\texttt{CALL GBIRK(Ehit)}$$

  3. x and y coordinate of the hit relative to the center of the scintillator plate must be stored if iEMCtype=3.

- **Processing the hits (digitization)**

  1. Take into account the light collection efficiency Ehit ⇒ Emeas:

     $$\texttt{CALL KOPIO\_SHASHLYK\_OPTICS(x, y, Ehit, Emeas)}$$

     Here, x and y are x and y coordinates of the hit relative to the center of scintillator plate. If iEMCtype=1 or iEMCtype=2 then Emeas=Ehit independently of the hit coordinates x and y.
  2. If $\texttt{iEMCtype} = \texttt{2}, \texttt{3}$ (lead/scintillator sandwich), take into account the light attenuation in the WLS fiber:

     $$\texttt{Emeas} = \texttt{Emeas} * \texttt{exp}((\texttt{nz} - \texttt{nzEMC}) * \texttt{dzEMC}/\texttt{fattEMC})$$

     Here, nz is the module layer number, other variables nzEMC, dzEMC, fattEMC are defined in Section 4. **This transformation should not be applied if the Shashlyk module is defined as a lead/scintillator mixture** (iEMCtype=1).
  3. For each module accumulate all hits:

     $$\texttt{Emod} = \sum_{hits \in module} \texttt{Emeas}$$

  4. Calibrate energy measured by the module:[2]

     $$\texttt{Emod} = \texttt{CnormEMC} * \texttt{Emod}$$

[2]Energy may be calibrated at the hit level.

5. Take into account the contribution of photo-statistics:[3]

$$\texttt{Emod} = \texttt{Emod} + \texttt{gunorm(CphstEMC)} * \texttt{sqrt(Emod)}$$

The real function `gunorm(s)` returns the value normally distributed with mean 0 and sigma `s`.

- **Further customization of the calorimeter signal**

  The parameters for these transformations are not predefined in the Shashlyk simulation package. This parameters are entered by the KOPIO GEANT input cards geometry.kopio.ffread.

  1. Rescale signal

     $$\texttt{Emod} = \texttt{CcorrEMC} * \texttt{Emod}$$

     This rescale may be useful, for example, to present the calorimeter signal in ADC counts instead of the deposited energy.

     Another possible application is related to the method of energy calibration. `CnormEMC` was defined as a ratio of the photon energy to the "visible" energy deposited in the scintillator (corrected by the light collection and light attenuation in the fiber). This was done in the special simulation with a narrow (1×1 cm^2) photon beam in the center of the 3×3 array of the modules. No electronic noise and thresholds were considered. Obviously the ratio of the real and the "detected" energy may depend on the rules of the determination the "visible" energy of the electromagnetic show (number of modules in the clump, thresholds etc.). `CcorrEMC` may serve to correct `CnormEMC` in accordance with the method of the counting of the energy of the clump.

  2. Add incoherent noise

     $$\texttt{Emod} = \texttt{Emod} + \texttt{gunorm(CnoiseEMC)}$$

     The definition of the `CnoiseEMC` should be consistent with the choice of `CcorrEMC`.

  3. Add coherent noise. For each calorimeter module the same value of

     $$\texttt{dE} = \texttt{gunorm(CcoheEMC)}$$

     for the current event is added:

     $$\texttt{Emod} = \texttt{Emod} + \texttt{dE}$$

The suggested scheme assumes the Analog-Digital-Converter (ADC) readout of the calorimeter signals. In the case of Wave Form Digitizers (WFD) the scheme may be significantly modified.

The user defined parameter `CfibrEMC` corresponds to the effective speed of the signal distribution in the WLS fibers. This value may be used to simulate the dependence of the time of the electromagnetic shower on the parameters of the shower. Currently, the default value is `CfibrEMC=0.5` speed of light in vacuum. However this value is not verified since the effect of the signal propagation in the fiber was not studied yet in the simulation of the Shashlyk module performance.

[3] The fluctuations due to photo-statistics may be accounted for at the hit level.

9 Comparison of the different types of modules

Three types of Shashlyk modules are currently considered in KOPIO GEANT. The selection of the module type is provided by the input card parameter `iEMCtype`. `iEMCtype=2` corresponds to the description of the Shashlyk module with as much detail as reasonably possible. The same geometry description is used for module `iEMCtype=3`, however in this case the light collection efficiency in the scintillator plate is taken into account in addition. For satisfactory simulation of the Shashlyk module, low energy cuts 10 KeV are required. As result, the intricacy of the geometry and low energy cuts lead to poor speed of the simulation. It takes about 0.3 sec on 700 MHz processor to simulate a 250 MeV photon shower.

Alternatively, the Shashlyk module may be approximated by the lead/scintillator mixture with density 2.6 g/cm^3 (`iEMCtype=1`). Simulation of the 250 MeV photon shower in such a module is about factor 30 faster. Since there is no sampling contribution to the energy resolution, the photo-statistic contribution should be increased, to obtain the total energy resolution about $3\%/\sqrt{E\ (\mathrm{GeV})}$.

The Monte Carlo gains, `calEMC(iEMCtype)`, and energy resolutions, `sigEMC(iEMCtype)`, were adjusted by simulation of the 250 MeV photon beam incident to the center of the 3×3 array of the Shashlyk modules. This simulation corresponds to the conditions of the photon test beam measurements of the calorimeter prototype. After adjustment, the Gaussian fit of the "measured" photon energy spectra gave a mean value 250.0 MeV and sigma 15.0 MeV $\left(3\%/\sqrt{E\ ((GeV)}\right)$

To compare the Monte Carlo performance of the different types of modules a larger size calorimeter (11×11 modules) was considered. The distributions of the "measured" energy and x-coordinate dispersions of the hits for modules `iEMCtype=1` and `iEMCtype=2` are shown in Fig. 5. Due to the larger size of the simulated calorimeter, the mean "measured" energy is greater than 250 MeV and energy resolution is better than $3\%/\sqrt{E\ ((GeV)}$. One can see that results for the two types of modules are in a good agreement with each other. It looks like the simplified module `iEMCtype=1` may be successfully used for many practical simulations. However, it must be underlined that this module does not contains holes for fibers and cracks between modules. So it should not be used in the simulations sensitive to the photon detection inefficiency.

The dependence of the calorimeter response on the size and the position of the photon beam is shown in Table 2 for all 3 types of module. There is only a negligible (about 10% of the R.M.S) dependence of the mean "measured" energies on the position of the beam. There is almost no difference between results for modules `iEMCtype=2` and `iEMCtype=3` (without and with light collection efficiency). However, it must be pointed out that the light collection efficiency matrix kopio_shashlyk_opteff.dat was obtained in Monte Carlo simulation. Though this simulation was adjusted with the special single scintillator plate measurements of the light collection efficiency, no experimental measurements of the dependence of the calorimeter signal on the position of the beam had been done recently.

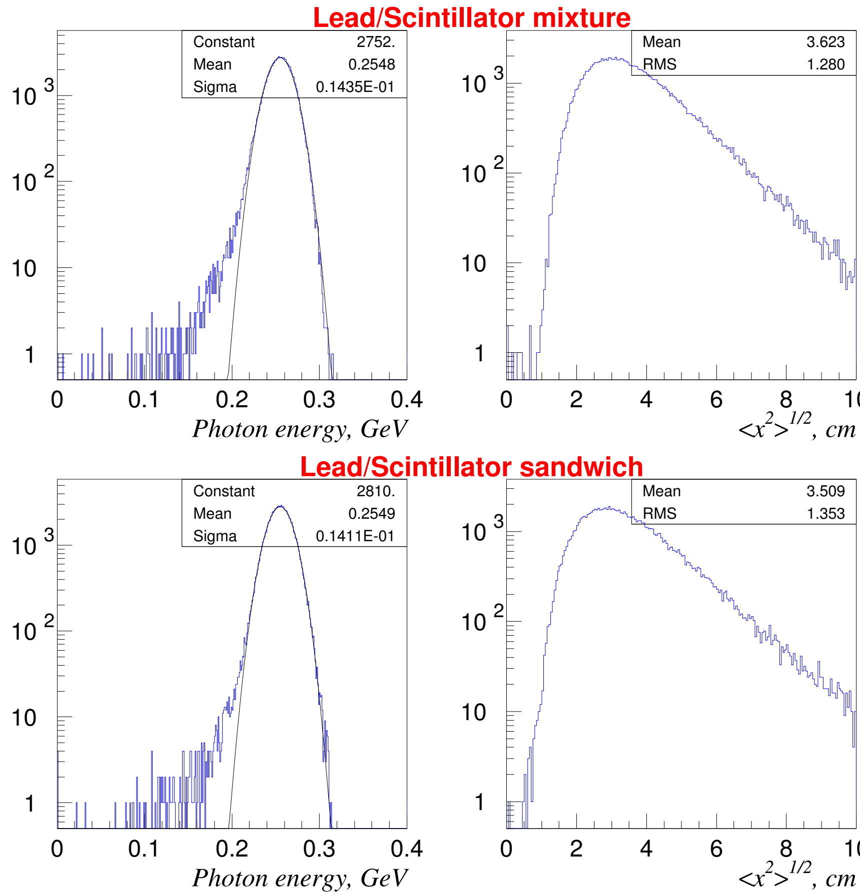

Figure 5: Comparison of the simulated calorimeter response on the type of the module. $\langle x^2 \rangle^{1/2}$ is the x-coordinate dispersion of the hits in the calorimeter.

250 MeV photon beam				Mean value and R.M.S. (MeV) of the signal					
x_c (cm)	y_c (cm)	Δ (cm)	σ_θ (mrad)	`iEMCtype=1`		`iEMCtype=2`		`iEMCtype=3`	
0.0	0.0	0.	0.	254.9	14.4	254.9	14.1	254.7	14.1
0.0	0.0	1.	2.	254.9	14.3	254.6	14.2	254.6	14.2
5.5	0.0	1.	2.	254.9	14.3	253.7	14.4	253.5	14.3
5.5	5.5	1.	2.	254.9	14.4	252.9	14.4	252.2	14.4
0.0	0.0	11.	2.	254.9	14.4	254.3	14.2	253.4	14.2

Table 2: The calorimeter signal dependence on the 250 MeV photon beam size and position. x_c and y_c are the coordinates of the center of the beam. Δ is the beam size. σ_θ is the beam angular dispersion.